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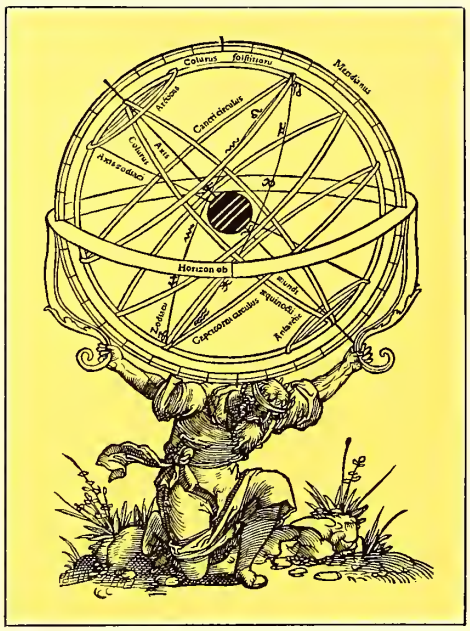

III. *Experimental Researches in Electricity.—Eighteenth Series.*

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§ 25. *On the electricity evolved by the friction of water and steam against other bodies.*

2075. TWO years ago an experiment was described by Mr. Armstrong and others*, in which the issue of a stream of high pressure steam into the air produced abundance of electricity. The source of the electricity was not ascertained, but was supposed to be the evaporation or change of state of the water, and to have a direct relation to atmospheric electricity. I have at various times since May of last year been working upon the subject, and though I perceive Mr. Armstrong has, in recent communications, anticipated by publication some of the facts which I also have obtained, the Royal Society may still perhaps think a compressed account of my results and conclusions, which include many other important points, worthy its attention.

2076. The apparatus I have used was not competent to furnish me with much steam or a high pressure, but I found it sufficient for my purpose, which was the investigation of the effect and its cause, and not necessarily an increase of the electric development. Mr. Armstrong, as is shown by a recent paper, has well effected the latter†. The boiler I used, belonging to the London Institution, would hold about ten gallons of water, and allow the evaporation of five gallons. A pipe $4\frac{1}{2}$ feet long was attached to it, at the end of which was a large stop-cock and a metal globe, of the capacity of thirty-two cubic inches, which I will call the *steam-globe*, and to this globe, by its mouth-piece, could be attached various forms of apparatus, serving as vents for the issuing steam‡. Thus a cock could be connected with the steam-globe, and this cock be used as the experimental steam-passage; or a wooden tube could be screwed in; or a small metal or glass tube put through a good cork, and the cork screwed in; and in these cases the steam way of the globe and tube leading to the boiler was so large, that they might be considered as part of the boiler, and these terminal passages as the obstacles which, restraining the issue of steam, produced any important degree of friction.

* Philosophical Magazine, 1840, vol. xvii. pp. 370, 452, &c. † Ibid. 1843, vol. xxii. p. 1.

‡ This globe and the pieces of apparatus are represented upon a scale of one-fourth in the Plate belonging to this paper.

2077. Another issue piece consisted of a metal tube terminated by a metal funnel, and of a cone advancing by a screw more or less into the funnel, so that the steam as it rushed forth beat against the cone (Plate I. fig. 2.); and this cone could either be electrically connected with the funnel and boiler, or be insulated.

2078. Another terminal piece consisted of a tube, with a stop-cock and feeder attached to the top part of it, by which any fluid could be admitted into the passage, and carried on with the steam (fig. 3.).

2079. In another terminal piece, a small cylindrical chamber was constructed (fig. 4.) into which different fluids could be introduced, so that, when the cocks were opened, the steam passing on from the steam-globe (2076.) should then enter this chamber and take up anything that was there, and so proceed with it into the final passage, or out against the cone (2077.), according as the apparatus had been combined together. This little chamber I will always call C.

2080. The pressure at which I worked with the steam was from eight to thirteen inches of mercury, never higher than thirteen inches, or about two-fifths of an atmosphere.

2081. The boiler was insulated on three small blocks of lac, the chimney being connected by a piece of funnel-pipe removable at pleasure. Coke and charcoal were burnt, and the insulation was so good, that when the boiler was attached to a gold-leaf electrometer and charged purposely, the divergence of the leaves did not alter either by the presence of a large fire, or the abundant escape of the results of the combustion.

2082. When the issuing steam produces electricity, there are two ways of examining the effect: either the insulated boiler may be observed, or the steam may be examined, but these states are always contrary one to the other. I attached to the boiler both a gold-leaf and a discharging electrometer, the first showed any charge short of a spark, and the second by the number of sparks in a given time carried on the measurement of the electricity evolved. The state of the steam may be observed either by sending it through an insulated wide tube in which are some diaphragms of wire gauze, which serves as a discharger to the steam, or by sending a puff of it near an electrometer when it acts by induction; or by putting wires and plates of conducting matter in its course, and so discharging it. To examine the state of the boiler or substance against which the steam is excited, is far more convenient, as Mr. Armstrong has observed, than to go for the electricity to the steam itself; and in this paper I shall give the state of the former, unless it be otherwise expressed.

2083. Proceeding to the cause of the excitation, I may state first that I have satisfied myself it is not due to evaporation or condensation, nor is it affected by either the one or the other. When the steam was at its full pressure, if the valve were suddenly raised and taken out, no electricity was produced in the boiler, though the evaporation was for the time very great. Again, if the boiler were charged by excited

resin before the valve was opened, the opening of the valve and consequent evaporation did not affect this charge. Again, having obtained the power of constructing steam passages which should give either the positive or the negative, or the neutral state (2102. 2110. 2117.), I could attach these to the steam way, so as to make the boiler either positive, or negative, or neutral at pleasure with the same steam, and whilst the evaporation for the whole time continued the same. So that the excitation of electricity is clearly independent of the evaporation or of the change of state.

2084. The issue of *steam alone* is not sufficient to evolve electricity*. To illustrate this point I may say that the cone apparatus (2077.) is an excellent exciter: so also is a box-wood tube (2102. fig. 5.) soaked in water, and screwed into the steam-globe. If with either of these arrangements, the steam-globe (fig. 1.) be empty of water, so as to catch and retain that which is condensed from the steam, then after the first moment (2089.), and when the apparatus is hot, the issuing steam excites no electricity; but when the steam-globe is filled up so far that the rest of the condensed water is swept forward with the steam, abundance of electricity appears. If then the globe be emptied of its water, the electricity ceases; but upon filling it up to the proper height, it immediately reappears in full force. So when the feeder apparatus (2078.) was used, whilst there was no water in the passage-tube, there was no electricity; but on letting in water from the feeder, electricity was immediately evolved.

2085. The electricity is due entirely to the friction of the particles of water which the steam carries forward against the surrounding solid matter of the passage, or that which, as with the cone (2077.), is purposely opposed to it, and is in its nature like any other ordinary case of excitement by friction. As will be shown hereafter (2130. 2132.), a very small quantity of water properly rubbed against the obstructing or interposed body, will produce a very sensible proportion of electricity.

2086. Of the many circumstances affecting this evolution of electricity, there are one or two which I ought to refer to here. Increase of pressure (as is well illustrated by Mr. Armstrong's experiments) greatly increases the effect, simply by rubbing the two exciting substances more powerfully together. Increase of pressure will sometimes change the positive power of a passage to negative; not that it has power of itself to change the quality of the passage, but as will be seen presently (2108.), by carrying off that which gave the positive power; no increase of pressure, as far as I can find, can change the negative power of a given passage to positive. In other phenomena hereafter to be described (2090. 2105.), increase of pressure will no doubt have its influence; and an effect which has been decreased, or even annihilated (as by the addition of substances to the water in the steam-globe, or to the issuing current of water and steam), may, no doubt, by increase of pressure be again developed and exalted.

2087. The shape and form of the exciting passage has great influence, by favouring

* Mr. Armstrong has also ascertained that water is essential to a high development. Phil. Mag. 1843, vol. xxii. p. 2.

more or less the contact and subsequent separation of the particles of water and the solid substance against which they rub.

2088. When the mixed steam and water pass through a tube or stop-cock (2076.), they may issue, producing either a hissing smooth sound, or a rattling rough sound*; and with the cone apparatus (2077. fig. 2.), or certain lengths of tube, these conditions alternate suddenly. With the smooth sound little or no electricity is produced; with the rattling sound plenty. The rattling sound accompanies that irregular rough vibration, which casts the water more violently and effectually against the substance of the passage, and which again causes the better excitation. I converted the end of the passage into a steam-whistle, but this did no good.

2089. If there be no water in the steam-globe (2076.), upon opening the steam-cock the *first effect* is very striking; a good excitement of electricity takes place, but it very soon ceases. This is due to water condensed in the cold passages, producing excitement by rubbing against them. Thus, if the passage be a stop-cock, whilst cold it excites electricity with what is supposed to be steam only; but as soon as it is hot, the electricity ceases to be evolved. If, then, whilst the steam is issuing, the cock be cooled by an insulated jet of water, it resumes its power. If, on the other hand, it be made hot by a spirit-lamp before the steam be let on, then there is *no* first effect. On this principle, I have made an exciting passage by surrounding one part of an exit tube with a little cistern, and putting spirits of wine or water into it.

2090. We find then that particles of water rubbed against other bodies by a current of steam evolve electricity. For this purpose, however, it is not merely water but *pure* water which must be used. On employing the feeding apparatus (2078.), which supplied the rubbing water to the interior of the steam passage, I found, as before said, that with steam only I obtained no electricity (2084.). On letting in distilled water, abundance of electricity was evolved; on putting a small crystal of sulphate of soda, or of common salt into the water, the evolution ceased entirely. Re-employing distilled water, the electricity appeared again; on using the common water supplied to London, it was unable to produce it.

2091. Again, using the steam-globe (2076.), and a box-wood tube (2102.) which excites well if the water distilling over from the boiler be allowed to pass with the steam, when I put a small crystal of sulphate of soda, of common salt, or of nitre, or the smallest drop of sulphuric acid, into the steam-globe with the water, the apparatus was utterly ineffective, and no electricity could be produced. On withdrawing such water and replacing it by distilled water, the excitement was again excellent: on adding a very small portion of any of these substances, it ceased; but upon again introducing pure water it was renewed.

* Messrs. Armstrong and Schafhaeutl have both observed the coincidence of certain sounds or noises with the evolution of the electricity.

2092. Common water in the steam-globe was powerless to excite. A little potash added to distilled water took away all its power; so also did the addition of *any* of those saline or other substances which give conducting power to water.

2093. The effect is evidently due to the water becoming so good a conductor, that upon its friction against the metal or other body, the electricity evolved can be immediately discharged again, just as if we tried to excite lac or sulphur by flannel which was damp instead of dry. It shows very clearly that the exciting effect, when it occurs, is due to water and not to the passing steam.

2094. As ammonia increases the conducting power of water only in a small degree (554.), I concluded that it would not take away the power of excitement in the present case; accordingly on introducing some to the pure water in the globe, electricity was still evolved though the steam of vapour and water was able to redden moist turmeric paper. But the addition of a very small portion of dilute sulphuric acid, by forming sulphate of ammonia, took away all power.

2095. When, in any of these cases, the steam-globe contained water which could not excite electricity, it was beautiful to observe how, on opening the cock which was inserted into the steam-pipe before the steam-globe, fig. 1. (the use of which was to draw off the water condensed in the pipe before it entered the steam-globe), electricity was instantly evolved; yet a few inches further on the steam was quite powerless, because of the small change in the quality of the water over which it passed, and which it took with it.

2096. When a wooden or metallic tube (2076.) was used as the exciting passage, the application of solution of salts to the outside and end of the tube in no way affected the evolution. But when a wooden cone (2077.) was used, and that cone moistened with the solutions, there was no excitement on first letting out the steam, and it was only as the solution was washed away that the power appeared; soon rising, however, to its full degree.

2097. Having ascertained these points respecting the necessity of water and its purity, the next for examination was the influence of the substance against which the stream of steam and water rubbed. For this purpose I first used cones (2077.) of various substances, either insulated or not, and the following, namely, brass, box-wood, beech-wood, ivory, linen, kerseymere, white silk, sulphur, caoutchouc, oiled silk, japanned leather, melted caoutchouc and resin, all became negative, causing the stream of steam and water to become positive. The fabrics were applied stretched over wooden cones. The melted caoutchouc was spread over the surface of a box-wood or a linen cone, and the resin cone was a linen cone dipped in a strong solution of resin in alcohol, and then dried. A cone of wood dipped in oil of turpentine, another cone soaked in olive oil, and a brass cone covered with the alcoholic solution of resin and dried, were at first inactive, and then gradually became negative, at which

time the oil of turpentine, olive-oil and resin were found cleared off from the parts struck by the stream of steam and water. A cone of kerseymere, which had been dipped in alcoholic solution of resin and dried two or three times in succession, was very irregular, becoming positive and negative by turns, in a manner difficult to comprehend at first, but easy to be understood hereafter (2113.).

2098. The end of a rod of shell-lac was held a moment in the stream of steam and then brought near a gold-leaf electrometer: it was found excited negative, exactly as if it had been rubbed with a piece of flannel. The corner of a plate of sulphur showed the same effect and state when examined in the same way.

2099. Another mode of examining the substance rubbed was to use it in the shape of wires, threads or fragments, holding them by an insulating handle in the jet, whilst they were connected with a gold-leaf electrometer. In this way the following substances were tried:—

Platinum,	Horse-hair,	Charcoal,
Copper,	Bear's hair,	Asbestus,
Iron,	Flint glass,	Cyanite,
Zinc,	Green glass,	Hæmatite,
Sulphuret of copper,	Quill,	Rock-crystal,
Linen,	Ivory,	Orpiment,
Cotton,	Shell-lac on silk,	Sulphate of baryta,
Silk,	Sulphur on silk,	Sulphate of lime,
Worsted,	Sulphur in piece,	Carbonate of lime,
Wood,	Plumbago,	Fluor-spar.

All these substances were rendered negative, though not in the same degree. This apparent difference in degree did not depend *only* upon the specific tendency to become negative, but also upon the conducting power of the body itself, whereby it gave its charge to the electrometer; upon its tendency to become wet (which is very different, for instance in shell-lac or quill, to that of glass or linen), by which its conducting quality was affected; and upon its size or shape. Nevertheless I could distinguish that bear's hair, quill and ivory had very feeble powers of exciting electricity as compared to the other bodies.

2100. I may make here a remark or two upon the introduction of bodies into the jet. For the purpose of preventing condensation on the substance, I made a platinum wire white-hot by an insulated voltaic battery, and introduced it into the jet: it was quickly lowered in temperature by the stream of steam and water to 212°, but of course could never be below the boiling point. No difference was visible between the effect at the first instant of introduction or any other time. It was always instantly electrified and negative.

2101. The threads I used were stretched across a fork of stiff wire, and the middle part of the thread was held in the jet of vapour. In this case, the string or thread, if held exactly in the middle of the jet and looked at end-ways to the thread, was

seen to be still, but if removed the least degree to the right or left of the axis of the stream it (very naturally) vibrated, or rather rotated, describing a beautiful circle, of which the axis of the stream was the tangent: the interesting point was to observe, that when the thread rotated, travelling as it were with the current, there was little or no electricity evolved, but that when it was nearly or quite stationary there was abundance of electricity, thus illustrating the effect of friction.

2102. The difference in the quality of the substances above described (2099.) gives a valuable power of arrangement at the jet. Thus if a metal, glass, or wood tube* (2076.) be used for the steam issue, the boiler is rendered well negative and the steam highly positive; but if a quill tube or, better still, an ivory tube be used, the boiler receives scarcely any charge, and the stream of steam is also in a neutral state. This result not only assists in proving that the electricity is not due to evaporation, but is also very valuable in the experimental inquiry. It was in such a neutral jet of steam and water that the excitation of the bodies already described (2099.) was obtained.

2103. Substances, therefore, may be held either in the neutral jet from an ivory tube, or in the positive jet from a wooden or metal tube; and in the latter case effects occurred which, if not understood, would lead to great confusion. Thus an insulated wire was held in the stream issuing from a glass or metal tube, about half an inch from the mouth of the tube, and was found to be unexcited: on moving it in one direction a little further off, it was rendered positive; on moving it in the other direction, nearer to the tube, it was negative. This was simply because, when near the tube in the forcible part of the current, it was excited and rendered negative, rendering the steam and water more positive than before, but that when further off, in a quieter part of the current, it served merely as a discharger to the current previously excited in the exit tube, and so showed the same state with it. Platinum, copper, string, silk, wood, plumbago, or any of the substances mentioned above (2099.), excepting quill, ivory, and bear's hair, could, in this way, be made to assume either one state or the other, according as they were used as exciters or dischargers, the difference being determined by their place in the stream. A piece of fine wire gauze held across the issuing jet shows the above effect very beautifully; the difference of an eighth of an inch either way from the neutral place will change the state of the wire gauze.

2104. If, instead of an excited jet of steam and water (2103.), one issuing from an ivory tube (2102.), and in the neutral state be used, then the wires, &c. can no longer be made to assume both states. They may be excited and rendered negative (2099.), but at no distance can they become dischargers, or show the positive state.

2105. We have already seen that the presence of a very minute quantity of matter able to give conducting power to the water took away all power of excitation (2090,

* A box-wood tube, 3 inches long and $\frac{1}{5}$th of an inch inner diameter, well soaked in distilled water and screwed into the steam-globe, is an admirable exciter.

&c.) up to the highest degree of pressure, i. e. of mechanical friction that I used (2086.); and the next point was to ascertain whether it would be so for all the bodies rubbed by the stream, or whether differences in degree would begin to manifest themselves. I therefore tried all these bodies again, at one time adding about two grains of sulphate of soda to the four ounces of water which the steam-globe retained as a constant quantity when in regular action, and at another time adding not a fourth of this quantity of sulphuric acid (2091.). In both cases all the substances (2099.) remained entirely unexcited and neutral. Very probably, great increase of pressure might have developed some effect (2086.).

2106. With dilute sulphuric acid in the steam-globe, varying from extreme weakness to considerable sourness, I used tubes and cones of zinc, but could obtain *no trace* of elcctricity. Chemical action, therefore, appears to have nothing to do with the excitement of electricity by a current of steam.

2107. Having thus given the result of the friction of the steam and water against so many bodies, I may here point out the remarkable circumstance of water being *positive* to them all. It very probably will find its placc above all other substances, even cat's hair and oxalate of lime (2131.). We shall find hereafter, that we have power, not merely to prevent the jet of steam and water from becoming positive, as by using an ivory tube (2102.), but also of reducing its own power when passing through or against such substances as wood, metal, glass, &c. Whether, with a jet so reduced, we shall still find amongst the bodies above mentioned (2099.) some that can render the stream positive and others that can make it negative, is a question yet to be answered.

2108. Advancing in the investigation, a new point was to ascertain what other bodies, than water, would do if their particles were carried forward by the current of steam. For this purpose the feeding apparatus (2078.) was mounted and charged with oil of turpentine, to be let in at pleasure to the steam-exit passage. At first the feeder stop-cock was shut, and the issuing steam and water made the boiler negative. On letting down the oil of turpentine, this state was instantly changed, the boiler became powerfully positive, and the jet of steam, &c. as strongly negative. Shutting off the oil of turpentine, this state gradually fell, and in half a minute the boiler was negative, as at first. The introduction of more oil of turpentine instantly changed this to positive, and so on with perfect command of the phenomena.

2109. Removing the feeder apparatus and using only the steam-globe and a wooden exit tube (2076.), the same beautiful result was obtained. With pure water in the globe the boiler was negative, and the issuing steam, &c. positive; but a drop or two of oil of turpentine, introduced into the steam-globe with the water, instantly made the boiler positive and the issuing stream negative. On using the little interposed chamber C (2079.), the effects were equally decided. A piece of clean new sail-cloth

Fig. 1.

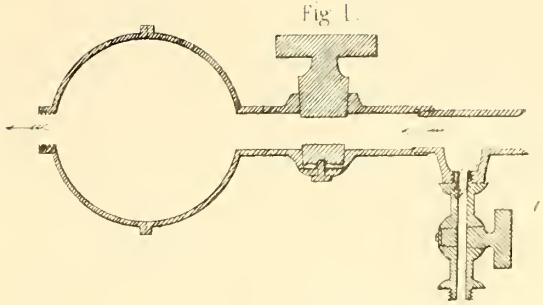

Fig. 2

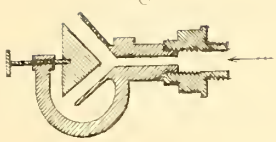

Fig. 4.

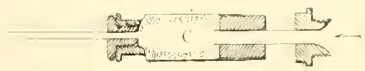

Fig. 3.

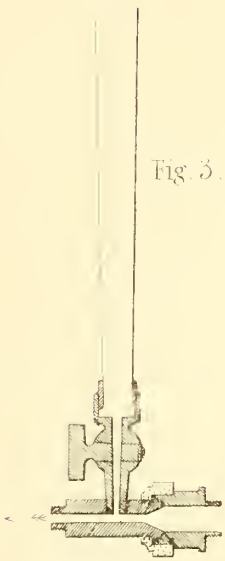

Fig. 5

Fig. 6.

J. Basire Lith.

was formed into a ring, moistened with oil of turpentine and placed in the box; as long as a trace of the fluid remained in the box the boiler was positive and the issuing stream negative.

2110. Thus the positive or negative state can be given at pleasure, either to the substance rubbed or to the rubbing stream; and with respect to this body, oil of turpentine, its perfect and ready dissipation by the continuance of the passage of the steam soon causes the new effect to cease, yet with the power of renewing it in an instant.

2111. With olive oil the same general phenomena were observed, i. e. it made the stream of steam, &c. *negative*, and the substance rubbed by it *positive*. But from the comparative fixedness of oil, the state was much more permanent, and a very little oil introduced into the steam-globe (2076.), or into the chamber C (2079.), or into the exit tube, would make the boiler positive for a long time. It required, however, that this oil should be in such a place that the steam stream, after passing by it, should rub against other matter. Thus, on using a wooden tube (2076. 2102.) as the exciter, if a little oil were applied to the inner termination, or that at which the steam entered it, the tube was made positive and the issuing steam negative; but if the oil were applied to the outer termination of the tube, the tube had its ordinary negative state, as with pure water, and the issuing steam was positive.

2112. Water is essential to this excitation by fixed oil, for when the steam-globe was emptied of water, and yet oil left in it and in the passages, there was no excitement. The first effect (2089.), it is true, was one of excitement, and it rendered the boiler positive, but that was an effect due to the water condensed in the passage, combined with the action of the oil. Afterwards, when all was hot, there was no evolution of electricity.

2113. I tried many other substances with the chamber C and other forms of apparatus, using the wet wooden tube (2102.) as the place and substance by which to excite the steam stream. Hog's-lard, spermaceti, bees'-wax, castor-oil, resin applied dissolved in alcohol; these, with olive-oil, oil of turpentine, and oil of laurel, all rendered the boiler positive, and the issuing steam negative. Of substances which seemed to have the reverse power, it is doubtful if there are any above water. Sulphuret of carbon, naphthaline, sulphur, camphor, and melted caoutchouc, occasionally seemed in strong contrast to the former bodies, making the boiler very negative, but on trying pure water immediately after, it appeared to do so quite as powerfully. Some of the latter bodies with oil-gas liquid, naphtha and caoutchoucine, gave occasionally variable results, as if they were the consequence of irregular and complicated effects. Indeed, it is easy to comprehend, that according as a substance may adhere to the body rubbed, or be carried off by the passing stream, exchanging its mechanical action from rubbed to rubber, it should give rise to variable effects; this, I think, was the case with the cone and resin before referred to (2097.).

2114. The action of salts, acids, &c., when present in the water to destroy its

effect, I have already referred to (2090, &c.). In addition, I may note that sulphuric ether, pyroxylic spirit, and boracic acid did the same.

2115. Alcohol seemed at the first moment to render the boiler positive. Half alcohol and half water rendered the boiler negative, but much less so than pure water.

2116. It must be considered that a substance having the reverse power of water, but only in a small degree, may be able to indicate that property merely by diminishing the power of water. This diminution of power is very different in its cause to that dependent on increasing the conducting power of the water, as by saline matter (2090.), and yet the apparent effect will be the same.

2117. When it is required to render the issuing steam permanently negative, the object is very easily obtained. A little oil or wax put into the steam-globe (2076.), or a thick ring of string or canvas soaked in wax, or solution of resin in alcohol, and introduced into the box C (2079.), supplies all that is required. By adjusting the application it is easy to neutralize the power of the water, so that the issuing stream shall neither become electric, nor cause that to be electrified against which it rubs.

2118. We have arrived, therefore, at three modes of rendering the jet of steam and water neutral, namely, the use of an ivory or quill tube (2102.), the presence of substances in the water (2090, &c.), and the neutralization of its natural power by the contrary force of oil, resin, &c. &c.

2119. In experiments of the kind just described an ivory tube cannot be used safely with acid or alkalies in the steam-globe, for they, by their chemical action on the substance of the tube, in the evolution or solution of the oily matter for instance, change its state and make its particular power of excitement very variable. Other circumstances also powerfully affect it occasionally (2144.).

2120. A very little oil in the rubbing passages produces a great effect, and this at first was a source of considerable annoyance, by the continual occurrence of unexpected results; a portion may lie concealed for a week together in the thread of an unsuspected screw, and yet be sufficient to mar the effect of every arrangement. Digesting and washing with a little solution of alkali, and avoiding all oiled washers, is the best way in delicate experiments of evading the evil. Occasionally I have found that a passage, which was in some degree persistently negative, from a little melted caoutchouc, or positive from oil, resin, &c., might be cleared out thoroughly by letting oil of turpentine be blown through it; it assumed for a while the positive state, but when the continuance of steam had removed that (2110.), the passage appeared to be perfectly clear and good and in its normal condition.

2121. I now tried the effect of oil, &c. when a little saline matter or acid was added to the water in the steam-globe (2090, &c.), and found that when the water was in such a state as to have no power of itself, still oil of turpentine, or oil, or resin in the box C, showed their power, in conjunction with such water, of rendering the

boiler positive, but their power appeared to be reduced: increase of the force of steam, as in all other cases, would, there is little doubt, have exalted it again. When alkali was in the steam-globe, oil and resin lost very much of their power, and oil of turpentine very little. This fact will be important hereafter (2126.).

2122. We have seen that the action of such bodies as oil introduced into the jet of steam changed its power (2108.), but it was only by experiment we could tell whether this change was to such an extent as to alter the electricity for few or many of the bodies against which the steam stream rubbed. With olive oil in the box C, *all* the insulated cones before enumerated (2097.) were made positive. With acetic acid in the steam-globe all were made neutral (2091.). With resin in the box C (2113.), all the substances in the former list (2099.) were made positive, there was not one exception.

2123. The remarkable power of oil, oil of turpentine, resin, &c., when in very small quantity, to change the exciting power of water, though as regards some of them (2112.) they are inactive without it, will excuse a few theoretical observations upon their mode of action. In the first place it appears that steam alone cannot by friction excite the electricity, but that the minute globules of water which it carries with it being swept over, rubbed upon and torn from the rubbed body (2085.) excite it and are excited, just as when the hand is passed over a rod of shell-lac. When olive oil or oil of turpentine is present, these globules are, I believe, virtually converted into globules of these bodies, and it is no longer water, but the new fluids which are rubbing the rubbed bodies.

2124. The reasons for this view are the following. If a splinter of wood dipped in olive oil or oil of turpentine touch the surface of water, a pellicle of the former instantly darts and spreads over the surface of the latter. Hence it is pretty certain that every globule of water passing through the box C, containing olive oil or oil of turpentine, will have a pellicle over it. Again, if a metal, wooden, or other balance-pan be *well cleaned* and *wetted* with water, and then put on the surface of clean water in a dish, and the other pan be loaded until almost, but not quite able to pull the first pan from the water, it will give a rough measure of the cohesive force of the water. If now the oily splinter of wood touch any part of the clean surface of the water in the dish, not only will it spread over the whole surface, but cause the pan to separate from the water, and if the pan be put down again, the water in the dish will no longer be able to retain it. Hence it is evident that the oil facilitates the separation of the water into parts by a mechanical force not otherwise sufficient, and invests these parts with a film of its own substance.

2125. All this must take place to a great extent in the steam passage: the particles of water there must be covered each with a film of oil. The tenuity of this film is no objection to the supposition, for the action of excitement is without doubt at

that surface where the film is believed to exist, and such a globule, though almost entirely water, may well act as an oil globule, and by its friction render the wood, &c. positive, itself becoming negative.

2126. That water which is rendered ineffective by a little saline or acid matter should still be able to show the effect of the film of oil (2121.) attached to it, is perfectly consistent with this view. So also is the still more striking fact that alkalized water (2092.) having no power of itself should deeply injure the power of olive oil or resin, and hardly touch that of oil of turpentine (2121.), for the olive oil or resin would no longer form a film over it but dissolve in it, on the contrary the oil of turpentine would form its film.

2127. That resin should produce a strong effect and sulphur not is also satisfactory, for I find resin in boiling hot water melts, and has the same effect on the balance (2124.) as oil, though more slowly; but sulphur has not this power, its point of fusion being too high.

2128. It is very probable that when wood, glass, or even metal is rubbed by these oily currents, the oil may be considered as rubbing not merely against wood, &c., but water also, the water being now on the side of the thing rubbed. Under the circumstances water has much more attraction for the wood rubbed than oil has, for in the steam-current, canvas, wood, &c. which has been well soaked in oil for a long time are quickly dispossessed of it, and found saturated with water. In such case the effect would still be to increase the positive state of the substance rubbed, and the negative state of the issuing stream.

2129. Having carried the experiments thus far with steam, and having been led to consider the steam as ineffectual by itself, and merely the mechanical agent by which the rubbing particles were driven onwards, I proceeded to experiment with compressed air*. For this purpose I used a strong copper box of the capacity of forty-six cubic inches, having two stop-cocks, by one of which the air was always forced in, and the other retained for the exit aperture. The box was very carefully cleaned out by caustic potash. Extreme care was taken (and required) to remove and avoid oil, wax, or resin about the exit apertures. The air was forced into it by a condensing syringe, and in certain cases when I required dry air, four or five ounces of cylinder potassa fusa were put into the box, and the condensed air left in contact with the substance ten or fifteen minutes. The average quantity of air which issued and was used in each blast was 150 cubic inches. It was very difficult to deprive this air of the smell of oil which it acquired in being pumped through the condensing syringe.

2130. I will speak first of undried common air: when such compressed air was

* Mr. ARMSTRONG has also employed air in much larger quantities. Philosophical Magazine, 1841, vol. xviii. pp. 133, 328.

let suddenly out against the brass or the wood cone (2077.), it rendered the cone negative, exactly as the steam and water had done (2097.). This I attributed to the particles of water suddenly condensed from the expanding and cooled air rubbing against the metal or wood: such particles were very visible in the mist that appeared, and also by their effect of moistening the surface of the wood and metal. The electricity here excited is quite consistent with that evolved by steam and water: but the idea of that being due to evaporation (2083.) is in striking contrast with the actual condensation here.

2131. When however common air was let out against ice it rendered the ice *positive*, again and again, and that in alternation with the negative effect upon wood and metal. This is strongly in accordance with the high positive position which has already been assigned to water (2107.).

2132. I proceeded to experiment with dry air (2129.), and found that it was in all cases quite *incapable* of exciting electricity against wood or sulphur, or brass, in the form of cones (2077. 2097.); yet if, in the midst of these experiments, I let out a portion of air immediately after its compression, allowing it no time to dry, then it rendered the rubbed wood or brass negative (2130.). This is to me a satisfactory proof that in the former case the effect was due to the condensed water, and that neither *air alone* nor *steam alone* can excite these bodies, wood, brass, &c., so as to produce the effect now under investigation.

2133. In the next place the box C was attached to this air apparatus and experiments made with different substances introduced into it (2108.), using common air as the carrying vehicle.

2134. With distilled water in C, the metal cone was every now and then rendered negative, but more frequently no effect was produced. The want of a continuous jet of air sadly interfered with the proper adjustment of the proportion of water to the issuing stream.

2135. With common water (2090.), or a very dilute saline solution, or very dilute sulphuric acid (2091.) or ammonia, I never could obtain any traces of electricity.

2136. With oil of turpentine only in box C, the metal cone was rendered positive; but when both distilled water and oil of turpentine were introduced, the cone was very *positive*, indeed far more so than before. When sent against ice, the ice was made positive.

2137. In the same manner olive oil and water in C, or resin in alcohol and water in C, rendered the cone positive, exactly as if these substances had been carried forward in their course by steam.

2138. Although the investigation as respects the steam stream may here be considered as finished, I was induced in connection with the subject to try a few experiments with the air current and dry powders. *Sulphur* in powder (sublimed) rendered

both metal and wood, and even the sulphur cone negative, only once did it render metal positive. *Powdered resin* generally rendered metal negative, and wood positive, but presented irregularities, and often gave *two states in the same experiment*, first diverging the electrometer leaves, and yet at the end leaving them uncharged. *Gum* gave unsteady and double results like the resin. *Starch* made wood negative. *Silica*, being either very finely powdered rock-crystal or that precipitated from fluo-silicic acid by water, gave very constant and powerful results, but both metal and wood were made strongly positive by it, and the silica when caught on a wet insulated board and examined was found to be negative.

2139. These experiments with powders give rise to two or three observations. In the first place the high degree of friction occurring between particles carried forward by steam or air was well illustrated by what happened with sulphur: it was found driven into the dry box-wood cone opposed to it with such force that it could not be washed or wiped away, but had to be removed by scraping. In the next place, the *double* excitements were very remarkable. In a single experiment, the gold leaves would open out very wide at first, and then in an instant as suddenly fall, whilst the jet still continued, and remains at last either neutral or a very little positive or negative: this was particularly the case with gum and resin. The fixation upon the wood of some of the particles issuing at the beginning of the blast and the condensation of moisture by the expanding air, are circumstances which with others present tend to cause these variable results.

2140. Sulphur is nearly constant in its results, and silica very constant, yet their states are the reverse of those that might have been expected. Sulphur in the lump is rendered negative whether rubbed against wood or any of the metals which I have tried, and renders them *positive* (2141.), yet in the above experiments it almost always made both negative. Silica, in the form of a crystal, by friction with wood and metals renders them *negative*, but applied as above, it constantly made them strongly positive. There must be some natural cause for these changes, which at present can only be considered as imperfect results, for I have not had time to investigate the subject.

2141. In illustration of the effect produced by steam and water striking against other bodies, I rubbed these other substances (2099.) together in pairs to ascertain their order, which was as follows:—

1. Catskin or bearskin.
2. Flannel.
3. Ivory.
4. Quill.
5. Rock-crystal.
6. Flint glass.
7. Cotton.
8. Linen, canvas.
9. White silk.
10. The hand.
11. Wood.
12. Lac.
13. Metals . . . Iron. Copper. Brass. Tin. Silver. Platinum.
14. Sulphur.

Any one of these became negative with the substances above, and positive with those beneath it. There are however many exceptions to this general statement: thus one part of a catskin is very negative to another part, and even to rock-crystal: different pieces of flannel also differ very much from each other.

2142. The mode of rubbing also makes in some cases a great difference, although it is not easy to say why, since the particles that actually rub ought to present the same constant difference; a feather struck lightly against dry canvas will become strongly negative, and yet the same feather drawn with a little pressure between the folds of the same canvas will be strongly positive, and these effects alternate, so that it is easy to take away the one state in a moment by the degree of friction which produces the other state. When a piece of flannel is halved and the two pieces drawn across each other, the two pieces will have different states irregularly, or the same piece will have both states in different parts, or sometimes both pieces will be negative, in which case, doubtless, air must have been rendered positive, and then dissipated.

2143. Ivory is remarkable in its condition. It is very difficult of excitement by friction with the metals, much more so than linen, cotton, wood, &c., which are lower in the scale than it (2141.), and withal are much better conductors, yet both circumstances would have led to the expectation that it would excite better than them when rubbed with metals. This property is probably very influential in giving character to it as a non-exciting steam passage (2102.).

2144. Before concluding this paper, I will mention, that having used a thin ivory tube fixed in a cork (2076.) for many experiments with oil, resin, &c., it at last took up such a state as to give not merely a non-exciting passage for the steam, but to exert upon it a nullifying effect, for the jet of steam and water passing through it produced no excitation against any of the bodies opposed, as on the former occasion, to it (2099.). The tube was apparently quite clean, and was afterwards soaked in alcohol to remove any resin, but it retained this peculiar state.

2145. Finally, I may say that the cause of the evolution of electricity by the liberation of confined steam is not evaporation ; and further, being, I believe, friction, it has no effect in producing, and is not connected with, the general electricity of the atmosphere: also, that as far as I have been able to proceed, pure gases, *i. e.* gases not mingled with solid or liquid particles, do not excite electricity by friction against solid or liquid substances*.

* References to papers in the Philosophical Magazine, 1840–1843. Armstrong, Phil. Mag. vol. xvii. pp. 370, 452; vol. xviii. pp. 50, 133, 328; vol. xix. p. 25; vol. xx. p. 5; vol. xxii. p. 1. Pattinson, Phil. Mag. vol. xvii. pp. 375, 457. Schafhaeutl, Phil. Mag. vol. xvii. p. 449; vol. xviii. pp. 14, 95, 265.

PLATE I.

Description of the Apparatus represented in section, and to a scale of one-fourth.

Fig. 1. The steam-globe (2076.), principal steam-cock, and drainage-cock to remove the water condensed in the pipe. The current of steam, &c. travelled in the direction of the arrow-heads.

Fig. 2. The cone apparatus (2077.) in one of its forms. The cone could be advanced and withdrawn by means of the milled head and screw.

Fig. 3. The feeding apparatus (2078.). The feeder was a glass tube or retort neck fitted by a cork into the cap of the feeding stop-cock. Other apparatus, as that figured 2, 5, 6, could be attached by a connecting piece to this apparatus.

Fig. 4. The chamber C (2079.) fitted by a cork on to a metal pipe previously screwed into the steam-globe; and having a metallic tube and adjusting piece screwed into its mouth. Other parts, as the cone fig. 2, or the wooden or glass tubes 5, 6, could be conjoined with this chamber.

Fig. 5. The box-wood tube (2102.).

Fig. 6. A glass or thin metal tube (2076.) attached by a cork to a mouth-piece fitting into the steam-globe.